Ecological
Research
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DRAFT REPORT

WATER QUALITY AND HYDROLOGY STUDIES AT SODA SPRINGS, SAN BERNARDINO COUNTY, CA.

Prepared for: Bureau of Land Management
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1.0 Summary and Conclusion

The chemical constituents of the ponds and well at Soda Springs reflect the history of the water in the Soda Lake aquifer. The relatively high concentrations of the ions sodium, chloride, bicarbonate and sulfate are common in desert waters that have their origin in alkaline playa deposits. All information we have been able to obtain from the literature and from our direct observations indicates the artesian flow at Soda Springs has its origin in waters which flow beneath the Soda Lake from the Mojave River Wash located to the south and west of Soda Springs. Deuterium isotope analysis of well water from Soda Springs indicates its source is from the high elevations of the San Bernardino Mountains. As the water flows along the bed of the Mojave River, there is a gradual concentration of ions due to evaporation. Surface flows normally only occur near Victorville and in Afton Canyon, approximately 85 miles to the east. As waters flow out of Afton Canyon they percolate into the Mojave River Wash which serves as the forebay for recharge of the Soda Lake aquifer. Clay layers beneath Soda Lake allow water to be conducted northward under a sufficient head of pressure to produce artesian flows at Soda Springs which are 6 to 10 feet above the surface of the dry lake bed.

At Soda Springs, one natural water body, M.C. Spring, is formed by this aquifer. Two man-made ponds, Lake Tuendae and Three Bats Pond also provide habitat for the endangered Mohave tui chub (Gila bicolor mohavensis). Water quality conditions in these three environments vary considerably, especially seasonally. M.C. Spring has the most equitable water quality for the chub in terms of temperature and ionic content. The other two ponds are much larger and hence are subject to considerable fluctuations in temperature, dissolved oxygen concentration and salinity. Winter temperatures as low as 6 C have been measured in Lake Tuendae and Three Bats Pond often has a salinity of 10.0 ppt in late summer.

The quality of water in both the aquifer and the ponds is not effected by the facilities of the Desert Studies Consortium at this time.

2.0 INTRODUCTION

2.1 Contracted Task Description

The intent of this contract was to perform an assessment of hydrologic conditions at Soda Springs, San Bernardino County, California. Special emphasis was to be focused on how both the conditions of the aquifer and the hydrology of the system relate to the maintenance of quality habitat for a federally endangered fish species, the Mohave tui chub, Gila bicolor mohavensis.

The Mohave tui chub has been listed as endangered on the Federal List of Endangered and Threatened Wildlife since October 13, 1970. Similarly, it has been listed by the State of California as endangered. This species is native to the Mojave River basin where it once occurred naturally throughout the lower reaches of the Mojave River. Due to hybridization with the introduced arroyo chub (Gila orcutti), the Mohave tui chub has been lost from its entire original range, with the exception of the Soda Springs area. In some remarkable manner, this relict of the ice ages has persisted until the present day. The hydrologic system at Soda Springs has been altered dramatically over the past century. Two artificial ponds now retain the majority of the Mohave tui chub population. A small spring, located along the ancient shoreline of Soda Lake also contains a small chub population. It could well be that this small spring was the refugium for this species at Soda Springs. As man began to modify the aquifer and create cisterns, holding tanks and reservoirs, the chubs probably were moved to these artificial water bodies and they continue to persist until today.

Recent modifications of the site have prompted this study of the aquifer as it pertains to the continued survival of this endangered species. In 1978, the Bureau of Land Management completed a Habitat Management Plan for Soda Springs in cooperation with the California Department of Fish and Game and the U.S. Fish and Wildlife Service. Subsequently, the Bureau of Land Management has completed a Multi-Resource Management Plan for the Soda Springs Area of Critical Environmental Concern (ACEC) as designated in the California Desert Plan of 1980 and the U.S. Fish and Wildlife Service has completed a draft recovery plan for the Mohave tui chub. The continued survival of the Mohave tui chub at Soda Springs is a central objective in that, until recently, it provided habitat for the only genetically pure populations of the Mohave tui chub. In the 1970's populations were established at Lark Seep on the China Lake Naval Weapons Center and in a small pond near the town of Hinkley, California.

2.2 Purpose for the Study

The purpose of this study is to make the most viable assessment possible of the hydrologic conditions in the Soda Springs area. Emphasis was placed on how these conditions relate to the maintenance of quality habitat for the Mohave tui chub, particularly in relation to projected facility use at Soda Springs. Recent changes at Soda Springs have involved the development of an education center by the California Desert Studies Consortium. A new restroom facility has been installed and a reverse osmosis water system will soon be operational. All of the existing fish habitats are dependent upon water from the aquifer and because the ponds are within the water table, hence the development of restroom and other facilities at Soda Springs could potentially have impacts upon the system. The U.S. Army Corps of Engineers have recently proposed a modification of the Mojave River Dam south of Victorville. Water flow during storm events would no longer move into the Soda Lake aquifer if the project is implemented. The affect of retention of recharge water, which normally moves down the Mojave River and out onto Soda Lake, on the hydrology of the Soda Spings system must also be considered.

2.3 Approach

With the limited financial resources provided in the contract, we have undertaken an examination of the hydrologic unit at Soda Springs. All existing literature on the Soda Springs system and surrounding area was reviewed and analyzed in view of producing a comprehensive understanding of the system. Aerial photographs of the site were obtained and examined using standard imagery analysis methods. Small diameter, shallow test wells were put into the aquifer in a number of locations. Water samples were taken to the Edward S. Babcock Laboratory in Riverside for chemical analysis. Pump tests were made in the field to determine the aquifer capacity.

2.4 Scope and Limitations

The objective of this study was to examine existing information on the hydrology and water quality of the Soda Springs aquatic system and conduct limited field investigations. Budgetary limitations of the contract were such that little hydrological work could be carried out. Existing information on the Soda Springs aquifer, however, was almost non-existent. A regional groundwater study on Soda Lake had been prepared in the late 1970's by Southern Califoria Edison (Dickey, et al, 1979). A more recent geohydrology study by Foster (1984) examined groundwater relationships of the area for a proposed mine to be constructed about 3 miles northeast of Soda Springs. These reports contributed some regional background on the aquifer but provide very little information on the Soda Springs system itself.

We thus found it necessary to place a series of small diameter test wells in the aquifer adjacent to the existing well and in the ajacent area. In addition, we were able to utilize a series of test wells put in concurrent to our investigation by geology students from California State University, Fullerton. We determined elevations using a surveyor's level of all test wells and the existing well and ponds. By examining the actual water level of these wells during pump draw down tests it was possible to obtain some original hydrological data on the Soda Springs aquifer.

Some water quality data was obtained from the Desert Studies Consortium staff. In addition, field measurements of water quality were made on four separate field trips to the site. Water samples were collected at three locations in January and June of 1985 for complete chemical analysis. The samples were taken to the Edward S. Babcock and Sons Laboratory in Riverside for analysis.

3.0 REGIONAL SETTING AND RELATIONSHIPS

3.1 Geologic - Hydrologic Basins

Soda Springs lies along the eastern margin of the dry bed of Soda Lake approximately 10 miles south of Baker, California at the northeastern boundary of the Mojave Desert. Soda Dry Lake and Silver Dry Lake, to the north of Baker, are the terminus of the Mojave River surface drainage system (see Figure 1). The Mojave River heads on the eastern slope of the San Bernardino Mountains. It flows through Victorville on the surface and then continues on eastward as a subterranean stream. At Afton Canyon the river again flows along the surface for several miles providing a narrow strip of riparian habitat in the otherwise arid eastern Mojave Desert. East of Afton Canyon and south of Soda Springs it enters the Mojave River immediately adjacent to the San Andreas fault system at the western boundary of the Mojave Desert region, the river flows through Barstow to Afton canyon in a well defined course. East of Afton Canyon and south of Soda Springs, it enters the Mojave River Wash. From there any flow is spread across the playa surfaces of Soda and Silver Dry Lakes. Soda Dry Lake is underlain by the Garlock - Death Valley Fault system. These two faults form the northern and eastern boundaries of the Mojave block. Past movement has created the mountain - basin terrain which is now filling with sediment.

The Mojave Desert - or block, is an intensely deformed and faulted region. Volcanic activity has reoccurred throughout the block and in adjacent regions to the north, east and south. It is a part of the continental plate which has been broken and ridden against by the northeastward pressing Pacific basin. The hundreds of miles of movement along the San Andreas fault and tens of miles of movement along the Garlock fault have acted to squeeze the block as if the two faults were attempting to close upon one another. The continuing fault movement is obvious in the western region of the Mojave, but less so in the eastern limits. The thick playa sediments also obscure fault locations.

Fault movements in some locations have occurred after the deposition of lake bed sediments, as sequential water level measurements in wells along the course of the Mojave River have shown abrupt drops at several sites; a strong indication of the "damming action" of faults (California Department of Water Resources, 1967). The displacement and recency of faulting can bear on the source and size of the local water supply of the Soda Springs facility - as discussed at the conclusion of this section and in Section 4. In general, the Mojave block is an area of continuing strong seismic activity.

The boundary of the local drainage basin is shown in Figure 1. The features and limits of the map are based on maps prepared by the Southern California Edison Company for a hydrological resources study of the Soda Lake aquifer (Dickey, et al., 1979). Basin boundaries indicated by the California Department of Water Resources (Bulletin 91-24) differ slightly, showing a more extensive area to the east. The disagreement is probably not significant. Figure 1 also shows the Mojave River's input by the several arrows along its course.

Desert basins are typically divided into three hydrologic units: 1) mountain masses composed of igneous and metamorphic rocks, considered to have no useful water bearing zones, 2) basin fills composed of ancient lake muds and fine sands and courser rubble locally washed out from the bordering mountains and 3) alluvial fans sloping outward from heads of canyons and composed of a broad size mixture of rock fragments and silts. Basin fills along the Mojave River generally are water bearing. The utility of the water depends upon the continuity and porosity of the sand layers and the evaporation or mixing of the source water with brine concentrates. The Soda Lake basin is filled with clays and clayey sands. The deepest exploratory wells are located only two miles northeast of Soda Springs. At their total depth of 1070 feet they remained in lake sediments and did not encounter the igneous rocks of the basin floor. Geophysical studies infer the sediment thickness of the Soda Lake basin to be as great as 2000 feet (Dickey et al, 1979).

In addition, alluvial fans may contain large quantities of high quality water. Those flanking high mountains such as the Sierra Nevada are examples. The eastern Mojave is not considered to have such a subterrainean water resource as most mountains ranges are too low and evaporation too high. Ideal local circumstances might provide a water supply for some uses. As discussed later, the Soda Springs fan does not appear to have such a resource.

3.2 Climatology

The climate of the area is strongly controlled by the barrier mountains of the San Bernardino range and the northward extending Sierra. Rainfall in these mountain ranges average about 40 inches annually. Within 15 miles to the east, the annual average drops to less than 8 inches. In the eastern Mojave, the rainfall average is approximately 4 inches (Jahns, 1954). As a general rule of thumb, low rainfalls of 4 to 6 inches are considered not to be capable of any measurable increases to surface or ground water supplies.

Temperature, humidity and the intensity-duration of sunlight, in that order, play the most important weather roles in moisture loss. A water loss of 6.6 feet over a one year period was measured in Silver Lake, north of Baker, after the 1983 flood (Blaney, 1957). This value has been commonly used as the evaporative loss for desert locations.

Temperature is probably the most significant of these factors. Field studies of the evaporative process by the senior author (Bilhorn, unpublished) show that 1 % changes in average daily air temperature and humidity are about equally significant and are about 30 times more important than a 1 % change in the daily total miles of wind passage. A 1 % change in daily solar energy by the shadowing of passing clouds or the seasonal change in sun angle also has, relatively, a much smaller effect.

In a regional consideration of water resources of the southern California area, significant reduction in evaporation doesn't occur until the lower mean temperature and higher humidity of the coastline are reached. The high temperature, low humidity, and high wind velocities at Soda Springs means that evaporative rates are a major factor effecting the aquifer in general and the ponds in particular. As described in Section 4, some differences in water quality at the stations examined in this study are probably caused by exposure to wind.

3.3 Basin Water Budget

A basin water budget attempts to identify and quantify all sources of water entering the basin and all withdrawals from it. The Soda Lake basin receives water from the Mojave River at its western boundary (see Figure 1). This recharge is in the form of underground seepage and, sporadically, surface flow during times of major storms in the San Bernardino Mountain watershed. Similarly, water enters across the southern border from the Kelso Valley. These waters flow northward past the town of Baker and into Silver Lake. Local rainfall is the remaining source of water. Each of these sources is difficult to measure and little rainfall data exists in this sparsely populated area. The siting study of basin water resources for a proposed power plant by Southern California Edison provides the only calculation of the basin water budget (Dickey, 1979). The estimates of annual recharge to the Soda Lake Basin are:

1. recharge from Afton Canyon	200 - 1400 acre feet/yr
2. recharge from Kelso Valley	450 - 450 acre feet/yr*
3. recharge from rainfall runoff	275 - 550 acre feet/yr
4. recharge from Kelso Wash	50 - 100 acre feet/yr
total recharge	975 - 2500 acre feet/yr

* the estimate of 450 ac ft/yr is apparently very approximate, not allowing calculation of upper and lower figures.

To provide a sense of scale for the above numbers, Soda Lake playa covers 30 square miles (19,200 acres). The minimum estimated recharge of 975 acre feet would cover the playa with about one half inch of water. The maximum estimate of 2500 acre feet would provide a depth of one and a half inches. In more meaningful terms, these volumes of water would raise the water table of the playa area roughly one and half inches and four and one half inches, respectively.

As evaporation is high (6.6 feet per year or 55 cm/day), the creation of a long term water supply depends upon percolation of river and storm water to sediments some distance below the ground surface. The most important forebay area within the Soda Lake basin (the area were surface water percolates into the ground and recharges the aquifer system) appears to be the Mojave Wash. Mojave River surface and underground (base) flows exit Afton Canyon and flow into the Mojave Wash. In the last 70 years at least 5 severe storm flows have flooded the Mojave Wash, East Cronese Lake and Soda and Silver Lakes. As an example of the extremes of desert river flow, the above figures were calculated from the long term yearly averages of 5 to 13 cubic feet per second (cfs) flow passing the Afton gauging station on the Mojave River. In the 1969 storm, peak flow at this gauge reached 18,000 cfs. In the 1978 storm the maximum flow was about 8,000 cfs (Dickey, et al., 1979).

It is uncertain how much storm flows contribute to the basin water supply. The playa surfaces of Soda and Silver Lakes, as in most desert basins, are so fine grained as to be nearly impervious to downward percolation. Therefore, most of the water lying on the playa surface leaves by evaporation. Subsurface flows are thus probably more important in recharge of the basin's aquifer. Surface water can be observed to be flowing in Afton Canyon year round. This flow, plus water below the surface must be a significant part of the recharge of the Soda Lake aquifer.

In terms of subsurface water, well and water table measurements show that the basin is nearly full. A substantial elevational gradient exists along which subsurface water flows into the Soda Lake basin. In the higher portion of the basin, the Mojave Wash forebay has a land surface elevation of about 1100 feet above mean sea level. The water level in wells of this area is at 1020 feet - 80 feet below ground level. Three miles eastward, the land surface is at 1030 feet and the water level is 25 feet beneath it. Within another 4 to 5 miles, at a point approximately 5 miles south of Soda Springs, the water table is at or very near the lake bed surface elevation of 950 feet. This condition exists northward to the area of Baker.

At Soda Springs, the water table in the playa has been measured during this study to be at the playa surface in the winter months (927 feet msl) with a drop of about 4 feet occurring (923 feet) by early summer. The water supply well (when not pumping) and M.C. Spring, however, have had, during the course of this study, constant levels at 933.4 feet msl and 929 feet msl, respectively. This elevation difference of 6 to 10 feet, an artesian condition, occurs when impermeable clays overlay water bearing sands. Higher elevations of the aquifer to the south are probably responsible for the fact that the well surface level at Soda Springs are at an elevation above that of the adjacent dry lake bed.

The 6 to 8 foot heads we measured are higher than previously cited. Dickey (1979) reported values for the artesian head at Soda Springs of about 2.5 feet. The literature figures he used are apparently based upon estimates from an older well or modified spring structure which did not have a high enough casing to contain the water column from overflowing.

As mentioned, artesian conditions exist when there is an uphill location which allows water to percolate beneath a confining clay layer (an aquatard). There are two such possibilities for the artesian condition at Soda Springs, either water flows from the basin sediments to the south or it arises from the alluvial fan sediments and fractured mountain rocks in the adjacent canyon area of the Soda Mountains. Chemical comparison of waters (disussed in section 3.4) indicates the likely source of the Soda Springs water as being the southern Soda Lake basin.

Most of the water which comes into the Soda Lake basin flows from the Mojave River Wash with some additions from the areas towards the east to Kelso. Water entering the basin at these locations percolates downward and, as it moves northward, becomes trapped or "confined" under the clay aquatards. Water which lies on top of the clays becomes "perched". Perched water and confined water bodies can become hydraulically isolated, depending upon the leakiness of the aquatards.

The shallower depths of the aquitard beneath the playa are probably somewhat leaky - allowing the water lost from the playa surface during the intense summer evaporation to be replaced in the cooler months by gradual upward movement. The deeper clays layers are sufficiently tight, however, to allow the pressure to develop and cause the 6 to 10 foot head at Soda Springs.

Without a series of deep observation wells, testing depths of as much as several hundred feet, the depth from which Soda Springs water is rising is uncertain. Review of the well data provided in the Edison report (Dickey, et al., 1979) reveals that several thick clay layers exist in wells south and north of Soda Springs. The continuity of these clay beds is unclear, however, as neither the geologic nor the geophysical logs indicate clear matching of sediments and the geometry does not easily fit a pattern of continuous lake bed sediments. Based upon the clays encountered in the U.S. Geological Survey (U.S.G.S.) cored test holes located 2 miles to the northeast of the facility, the base of the clay aquatard would be about 70 feet beneath the playa surface at Soda Springs. A somewhat thicker clay encountered in Edison's Site No. 5 test well, 3.5 miles to the south, would probably be 110 to 130 feet deep at Soda Springs.

Lacking test wells and knowledge of the stratigraphic sequence of the sediments in the lake bed at the Soda Springs site, we can only suggest the above clay layers at 70 and 130 feet as plausible minimum depths to a water bearing formation under artesian pressure.

Faulting of the playa sediments could be a major factor in the depth of the water source and its areal extent. The existance and location of faults for the Soda Lake system are not completely understood. Some information on fault locations does exist, however. The fault shown in Figure 1 is taken from maps prepared by T.W. Dibblee, Jr. (Dibblee, 1980). The Edison report shows none, unpublished field maps of the U.S.G.S. and their Bulletin No. 91 -13, show a fault somewhat to the east. If the fault has had activity recent enough to displace playa sediments, the Soda Springs water source could be isolated to some degree from ground water withdrawls to the north such as the proposed Lago de Sosa mining venture.

The water losses from the basin, or outputs, are summarized in the Edison report as follows:

Domestic wells (at Baker)	650 acre feet/year
Irrigation wells (at Balch)	1,300 acre feet/year
Phreatophyte transpiration	6,000 to 9,500 acre feet/year
Surface soil evaporation	2,500 to 10,000 acre feet/year
total output	10,450 to 21,450 acre feet/year

The above summary shows that very little of the water loss is atributable to consumptive uses. The report did not include Soda Springs water consumption which we calculate to be on the order of only 50 acre feet (discussed in Section 4.4).

Comparison of the above output estimates of 10,500 to 21,500 acre feet with the estimated inputs of 975 to 2500 acre feet shows that discharge exceeds recharge by about 10 times. Such "overdrafting" should be apparent over time by lowered well levels or dried springs. As noted earlier, the near ground surface elevations of the water table - from the Mojave River Wash northward to Baker, indicate the basin sediments are nearly full of water. The continued existance of the springs and seeps at Soda Springs in spite of this apparent overdraft is evidence supporting some continuity to the water supply rather than a prominant decline. The few well records for Soda Springs have only brief descriptions and some land elevations do not agree with present data. We cannot determine therefore if there has been some loss of volume in the Soda Lake basin which would be caused by a lowering water table in the Mojave Wash area.

The only reference found which might imply some loss of spring volume is a now destroyed well at "Iron Springs", located near the edge of reeds 40 feet south of the limestone hill and 150 feet east of the railroad bed. Hydrophytic vegetation is present in this area, but an extensive marsh is not present. The reference, made in a 1965 U.S.G.S. well ticket for well 12N/8E-11L1, may be for this 103 foot deep well. It was dug in 1917, flowed or leaked for many years, producing a marshy area - then became plugged by accident or design.

In Bulletin No. 91-13 (Moyle, 1967), a long term lowering in water level is noted in the Baxter - Crucero area, the recharge forebay for the Soda Lake basin. The drop was 25 feet in the 46 year period of 1919 to 1965. The report continues with the comment that between Crucero and Silver Lake, "no significant change is indicated". Thus the Soda Lake basin seems to not show a similar decrease in its water table.

We have located and studied one well record in the Soda Lake basin which shows a decline in water levels (State well No. 12N/8E-27N2) with a series of measurements from 1954 to 1970. It is located at the Rasor Ranch, about 3.8 miles south of Soda Springs. The 27 foot deep well shows a drop in water level of 2 feet over the 16 year record period. Although the records indicate the well was actively pumped as late as the last measurement in 1970, no pumpage quantities are given. Without knowing the volume of the withdrawl, it is uncertain how far this 2 foot lowering extends and how significant it is to Soda Springs.

If an equilibrium between basin recharge and withdrawl exists, and the available data seems to indicate that the aquifer in the Soda Lake basin has maintain itself at a relatively constant level, corrections in either or both the input or output quantities must be made. The Edison report suggest that basin rainfall, particularly hard desert thunderstorm rainfall, may be underestimated. Within the scope of this study we cannot provide substantiated corrections to the Edison report figures. We, in fact, have some question that the evaporation figures may be low, leading to an even greater discrepancy in the water balance for the Soda Lake system.

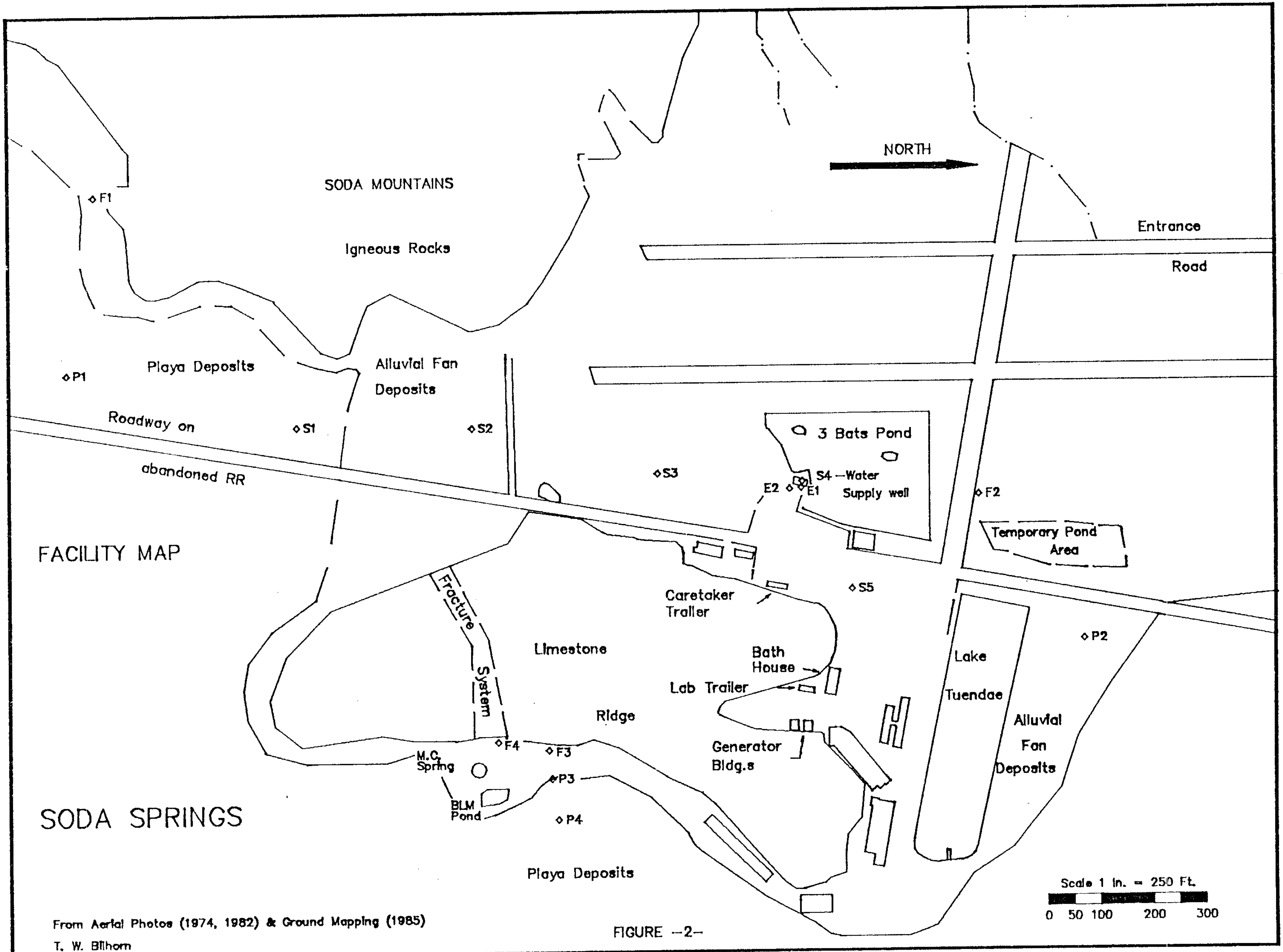
In total, the information available to us indicates that the water table to the south of Soda Springs is declining. This decline in the forebay area, the likely source of the hydrostatic pressure producing the springs to the north, would eventually reduce the Soda Springs well elevation and spring flow. If flows down the Mojave River were reduced or stopped by a dam upstream, recharge to the system would definitely be affected. Certainly, the Mojave River input must be a major source of water to the Soda Lake basin.

Section 3.4 Chemical Properties of Basin Water

The chemical makeup of the waters of the basin have been reviewed for the purpose of establishing the likely source of the Soda Springs water and the potential for a supply of higher quality water, possibly for drinking.

The alluvial fan which underlies the buildings, roads, lake and pond of the facility (see Figure 2) extends up into the large canyon to the west. It has a considerable surface area and, if the combination of rainfall and geologic conditions were favorable, the fan could contain a useful supply of water. If the igneous rock complex which makes up the Soda Mountains was extensively fractured, the supply would be substantially greater.

The chemical compositions of alluvial or fracture system water generally show low concentrations of salts and are often of drinking water quality. On the other hand, playa ground waters have high mineral



SODA SPRINGS
FACILITY MAP
NORTH
SODA MOUNTAINS
Igneous Rocks
Entrance
Road
Playa Deposits
Alluvial Fan
Deposits
Roadway on
abandoned RR
P1
F1
S1
S2
S3
S4 —Water
Supply well
S5
E1
E2
F2
F3
F4
P2
P3
P4
3 Bats Pond
Temporary Pond
Area
Caretaker
Trailer
Bath
House
Lab Trailer
Generator
Bldg.s
Limestone
Ridge
Fracture
System
M.C.
Spring
BLM
Pond
Lake
Tuendae
Alluvial
Fan
Deposits
Playa Deposits
Scale 1 in. = 250 Ft.
0 50 100 200 300
From Aerial Photos (1974, 1982) & Ground Mapping (1985)
T. W. Bilhorn

FIGURE —2—

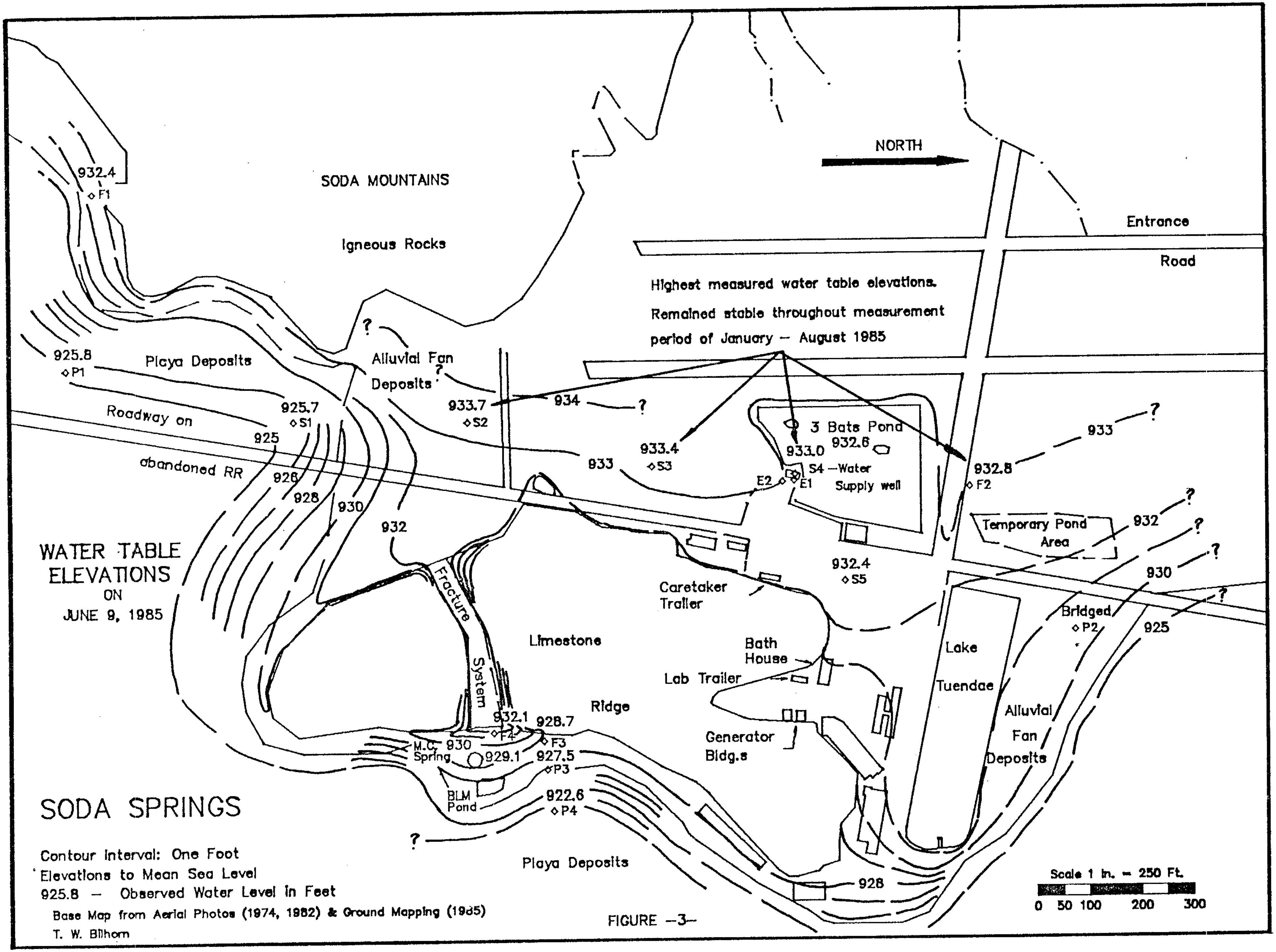

SODA MOUNTAINS
Igneous Rocks
NORTH
Entrance
Road
Highest measured water table elevations.
Remained stable throughout measurement
period of January – August 1985
Alluvial Fan
Deposits
932.4
◇F1
925.8
◇P1
Playa Deposits
Roadway on
abandoned RR
925.7
◇S1
925
926
928
930
932
933.7
◇S2
934
933
933.4
◇S3
3 Bats Pond
932.6
933.0
S4 –Water
Supply well
E2
E1
932.8
◇F2
Temporary Pond
Area
932.4
◇S5
Caretaker
Trailer
Fracture
System
Limestone
Ridge
Bath
House
Lab Trailer
Generator
Bldg.s
Lake
Tuendae
Bridged
◇P2
Alluvial
Fan
Deposits
932.1
◇F4
928.7
◇F3
M.C. Spring
930
929.1
927.5
◇P3
BLM
Pond
922.6
◇P4
Playa Deposits
928
WATER TABLE
ELEVATIONS
ON
JUNE 9, 1985
SODA SPRINGS
Contour Interval: One Foot
Elevations to Mean Sea Level
925.8 – Observed Water Level in Feet
Base Map from Aerial Photos (1974, 1982) & Ground Mapping (1985)
T. W. Bilhorn
Scale 1 in. = 250 Ft.
0 50 100 200 300

FIGURE –3–

concentrations. We have collected and analyzed samples of the main supply well (S4) and M.C. Spring. Table 1 shows the results of these analyses.

Comparisons of the Soda Springs well data were made with wells reported in the Edison study and with wells in the Baker area, reported in Bulletin 91-13. Table 2 summarizes these data. Edison drilled 6 groundwater tests to the south of Soda Springs. The mineral content of the main supply well at Soda Springs, compares closely to tests No. 2,3,4 and 5 located out on the playa. The best comparison in terms of quality is with test No. 3, located 6.5 miles south. This well penetrated a zone from 42 to 200 beneath ground level. Well No. 5, about 2.5 miles nearer, tested an interval from 38 to 300 feet deep. The recovery of water from sediments deeper than 100 feet in this well could account for the slightly different chemical concentrations when water from well No. 5 is compared to the Soda Springs supply well.

TABLE 1. - CHEMICAL ANALYSES OF WELL AND SPRING

CONSTITUENT	WATER SUPPLY WELL S4* (12N/8E-11E1) RESULT	M.C. SPRING RESULT
Total Hardness as $CaCO_3$	83 mg/L	63
Calcium	23 mg/L	15
Magnesium	6 mg/L	6
Sodium	730 mg/L	650
Potassium	14 mg/L	14
Total Cations	33.74 me/L	29.87
Total Alkalinity as $CaCO_3$	245 mg/L	213
Hydroxide	none	none
Carbonate	none	none
Bicarbonate	299 mg/L	259
Sulfate	400 mg/L	295
Chloride	710 mg/L	690
Nitrate	5 mg/L	4
Total Anions	33.31 me/L	29.90
Arsenic	0.02 mg/L	0.05
Boron	3.3 mg/L	3.1
Total Dissolved Solids	2190 mg/L	1936

Analysis performed by Babcock and Sons of samples collected 6/9/85. Units are milligrams (mg) and millequivelants (me) per liter.

* Well sample was taken from pump discharge after 1/2 hour of pumping.

TABLE 2. - CHEMICAL ANALYSES OF BASIN WELLS

Constituent	Site #1	Site #2	Site #3	Site #4	Site #5	14N/9E 30F1	14N/9E 30K1
pH	8.3	8.0	8.2	8.1	7.8	8.2	7.7
Calcium mg/L	38	20	26	140	190	30	27
Magnesium	14	2.9	7.0	8.3	8.0	29	33
Sodium	350	180	780	1100	720	270	256
Potassium	8.9	9.4	13	17	28	11	11
Carbonate	32	2	48	16	--	0	0
Bicarbonate	240	205	322	40	158	306	296
Sulfate	204	102	141	510	1170	168	176
Chloride	300	110	890	1600	540	249	252
Nitrate	0.7	0.6	0.2	0.4	0.2	8.5	9.5
Boron	--	--	--	--	--	1.2	1.2
Total Dissolved Solids	1200	600	2200	3500	2700	922	1020

Sites #1 through #5 are Southern California Edison wells, reported in "Soda Lake Groundwater Investigation, Phase II". The remaining wells are located in the vicinity of Baker. Data were taken from California Department of Water Resources Bulletin No. 91-13.

Isotope studies can be used to indicate sources of ground water. We were able to coordinate the sampling and analysis of water from the facility supply well, S4 (listed as 12N/8E-11E1 by U.S.G.S. personnel) for deuterium isotope ratio determination. The sample was taken during our March, 1985 site visit by U.S.G.S. staff and analyzed by their laboratories. The numerical value determined by the U.S.G.S. and made available to us is a measure of the reduction in quantity of the deuterium isotope when compared to the amount in sea water - the source of water vapor which condenses into rain or snow and becomes the local surface or groundwater supply.

Collections of rain water at stations in the Mojave Desert (Smith, 19) give deuterium content values ranging from -36 to -59. A sample from Kelso had a value of -51. The deuterium value for the Soda Springs well was -75. The loss of deuterium isotope is related to the temperature at the time of condensation. Because air temperatures in mountain regions are cooler, water which originates from precipitation at higher elevations usually have lower values. Common values for rain and snow in the Sierra range from -75 to -125. The deuterium data thus strongly suggests that the water in the well at Soda Springs has a distant source in the San Bernardino Mountains and not from some local source. The importance of the Mojave River system to the continued maintainence of water at Soda Springs thus becomes more evident. Water in the supply well probably does not come from the aquifer of the alluvial fan immediately to the west of the well.

Section 3.5 Conclusions and Potential Impacts

The available water level data, geometry of the land surface and underlying clay layers and chemical comparisons lead us to conclude the

Soda Springs water supply originates in the San Bernardino Moutains, flows down the Mojave River and then comes to Soda Springs via the playa sediments. The artesian pressure is created by the elevation of the forebay recharge area in the Mojave Wash and entrapment of the water under clay aquatards as it moves northward towards Baker.

Based upon the deuterium data, the sampled well water from Soda Springs is most comparable to water condensed above high mountain elevations such as those existing in the San Bernardino area - upper Mojave River watershed area.

As we stated previously, a decline in the water table in the forebay area appears to be occurring. We conclude that any substantial reduction to the output of the Mojave River to the Mojave Wash forebay area, will cause an eventual reduction in the spring flows at Soda Springs. With the data and time available to us we cannot predict by how much and within what period of time this predicted reduction will occur.

In the local Soda Springs area, the proposed mining operation "Lago De Sosa" has drilled a well indicated to be on the north boundary of land section 25, Township 13 North, Range 9 East. The location is 3.5 miles north of Soda Springs. Production is reported to be from a zone at 380 feet (Foster, 1984). The Foster report concludes that the water source for this well is also the Mojave Wash forebay and further concludes that the Soda Springs water source is the adjacent Soda Mountains - coming from rainfall percolating into fractures within the metavolcanic rocks which make up the mountain mass.

We have made some simple theoretical calculations of the possible rainfall recharge of the alluvial fan at the facility. From these calculations it would seem possible that the fan could contain a useful quantity of water. However, this water should be nearly fresh. As described above, the analyses of our water samples at the site and those of others show chemical concentrations high in minerals which match playa water.

The 75 ^{o}F (24 ^{o}C) well water temperature at Soda Springs does not necessarily indicate a very deep source as the Foster report suggests. Well records indicate temperatures in the low 70's to be commonplace throughout the Soda Lake basin as groundwater temperatures approximate seasonal average air temperatures.

We conclude that the Lago De Sosa well is very possibly producing from depths close enough to the depths suppling the Soda Springs system to have some hydraulic connection. Too little is known of the aquifer system to calculate potential impacts of high volume withdrawals by the mining operation on the Soda Springs aquifer.

SECTION 4.0 LOCAL SETTING AND RELATIONSHIPS

The hydrologic analysis of the Soda Springs facilities is based upon three site visits in January, March and June of 1985 and two preliminary visits made in June and September of 1984. Two meetings were held with Desert Studies Consortium staff in Fullerton. Figures 2 and 3 were prepared from field mapping on a 1 inch = 100 feet enlargement of a vertical aerial photograph dated August, 1974. We also used high altitude color vertical aerial photographs dated 14 May, 1982. These materials were kindly supplied by the Desert Studies Consortium.

We were able to coordinate our field investigations with geology student studies under the direction of Dr. Prem Saint of California State University, Fullerton. Shallow, water level observation wells were installed by the students at a number of locations in the local area. We provided identification of their location on the large scale aerial photograph and survey of their elevation, tying to the U.S. Coast and Geodetic bench mark located approximately three quarters of a mile to the southwest of the facility. We also installed two shallow observation wells (E1 and E2) near the water supply well (designated S4). These were used for our test of the capacity of the well. The location of the observation wells and their designation is shown on Figure 2. Included in this observation network are four water level staffs which we installed as follows:

1) the southeast corner of 3 Bats pond.
2) the southwest corner of Lake Tuendae.
3) in the north-center of M.C. Spring.
4) at the west edge of "BLM" pond - the constructed pond.
5) 25 feet northeast of M.C. Spring.

The elevations above mean sea level of the top of the well casings and top of the water level staffs are included as an appendix to this report. We believe the relative accuracy of the well and staff network to be about 0.25 feet. The accuracy of the height above the benchmark is probably within 1.0 foot.

All measurements and analyses reported here are those of the authors or their contracted laboratories. Measurements of the levels of the student wells has given us a greatly expanded view of the local groundwater system. The installation of the observation well network involved a considerable amount of effort - far beyond that possible within the scope of this contract.

Pump usage information has been supplied to us by Mr. Alan Romspert. coordinator of the Desert Studies Consortium and Mr. Tim Stroud, facility caretaker. Mr. Stroud also assisted in the surveying and well tests.

4.1 Ponds, Springs and Wells

Within the Soda Springs facility there is the main supply well and four ponds containing water year-round. A fifth area, labeled "temporary pond area" in Figure 2, lies just west of Lake Tuendae, across the abandoned railroad bed. Water had been pumped into this area in late 1984 for the temporary holding of fish; we also pumped water into this pond during our well test in January.

Our searches of hydrological records in federal and state agencies has provided little useful information on the history or geology of the wells and springs. Unfortunately, even the current water supply well is not on record with the U.S.G.S. or the California Department of Water Resources.

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Lake Tuendae

Located on the northern edge of the alluvial fan, in front of the main buildings of the old Zzyzx resort, Lake Tuendae is the largest of the constructed ponds. It is rectangular in overall shape with a width of 120 feet and length of 500 feet. The eastern end is curved. Lake Tuendae has a surface area of 62,300 square feet and it is supplied heavily by pumping from the supply well, S4. After dredging of the west end in early 1985, the volume of Lake Tuendae is about 80,000 cubic feet (2240 cubic meters) or 1.8 acre feet. Maximum depth is now about 3.3 feet in a small area near the northwest corner and near the pier structure at the east end.

Water pumped from the well to Lake Tuendae is discharged through a fountain located at the center of the small lake. Aerial photographs indicate a persistent area of seepage from the lake at the sloping alluvial fan edge along its north side. BLM staff have informed us that during the dredging operation small pumps were unable to keep the excavation dry. The lake is undoubtedly receiving and loosing some water through lateral percolation from the water table in addition to the gains and losses by pumpage and evaporation. Lake Tuendae is the largest aquatic habitat at the facility for the Mojave chub.

Three Bats Pond (West Pond)

This excavated pond is located between the supply well, S4, and the east - west section of the entrance road. It has a surface area of 41,000 square feet. Based upon depth measurements taken in August, 1981 (Taylor, 1982), Three Bats pond has a volume of approximately 90,000 cubic feet (2500 cubic meters). The deepest sections are at the southern end and average 2.5 feet with one hole at the southwest corner of 4 feet. Most of the pond has depths ranging from 1 to 1.5 feet. Heavy aquatic weed growth makes it difficult to take accurate depth soundings.

Unlike Lake Tuendae, Three Bats Pond is not replentished by pumping. In August we responded to a Barstow BLM office inquiry on the apparent low water level of the pond by advising that pumping to the pond would be needed to lower the salinity from its then near toxic level (physiological tolerance tests on the Mohave chub indicate salinities above 10 ppt are potentially lethal, McClanahan, et al., 1985). Desert Consortium staff (Romspert, 1985) informed us, however, that they have never seen this pond go dry. In rechecking all observations taken by us and supplied to us by BLM in August and September, we find the pond water level has fluctuated only 0.3 feet (9 cm.) and is at an elevation of about 932.5 feet above mean sea level. In mid-summer the water level was depressed about 0.5 feet below the local water table.

BLM Pond

This excavated pond has not been named to our knowledge, but was constructed by the BLM some time in the last 10 years. It lies 25 feet to the north and east of M.C. Spring, at the edge of the narrow band of outwash material skirting the limestone hill. The surface area, when full is 900 sguare feet. The excavation slopes downward gradually from the northern edge and exposes clayey material of the playa sediments. By June 8, 1985 the pond was nearly dry and had a water level elevation of 924 feet msl. On April 2, 1985 the elevation was 927.5 msl - 3.5 feet higher. The volume when full is estimated to be 2700 cubic feet. In June, it was less than 1000 cubic feet.

M.C. Spring

M.C. spring lies about 40 feet east of the base of the limestone hill, on the slope which transitions between the hill and the playa surface. Heavily overgrown with cattails, the dimensions are partly obscurred. The spring is nearly circular in shape with a diameter of 18 feet and surface area of 250 square feet. In June, cattail growth nearly covered the entire surface. Growth was thick enough to support our weight for a distance of about 3 feet from the bank. Water depth at the spring's center is about 5 feet. Within the fringing cattails the depth is 0.5 feet or less. We estimate the volume to be about 1000 cubic feet.

Throughout our observations, M.C. Spring water level has remained constant at 929 feet msl. Spring temperature (24 $^{\circ}$C) and chemical properties also remained very constant, in contrast to the characteristics of the adjacent BLM Pond.

The hydrologic records we have received make no mention of this spring by name or location. We understand that the Bureau of Land Management excavated BLM Pond to avoid any alteration of the spring. The circular shape and nearby rubble suggest some alteration in the past. A shallow ditch structure, now overgrown and collapsed, leads eastward from the spring onto the playa. By its present appearance, it probably did not lower the spring water level greatly. The intent of the ditch is unknown. It may have been an attempt to support salt evaporation operations such as those a few hundred feet to the south.

Other Springs or Seeps

Within the immediate area of the facility, there are no other individual bodies of standing water. Marshy seep areas do exist and indicate spring conditions with either insufficient topographic depression or volume of flow to maintain an open water body. Older well records describe a spring in the general location of the water supply well S4 - Three Bats pond. The spring was reported dynamited to create a shallow well.

The playa area adjacent to the south tip of the limestone hill shows a broad area of moisture darkened soil. This is the location of "Iron Springs" and two, now abandoned wells. The deeper 103 foot well was drilled through the limestone which is not a good conductor of water unless heavily fractured. The shallower well only penetrated the water table aquifer of the playa. Poor flow capacity, as demonstrated by our measurements of the dropping playa water table level in the summer months, would also limit this well's flow volume.

Several seeps are visible throughout the year along the access road north to Highway 15. Aerial photographs show the largest area to extend for 1.5 miles south from the north line of land section 35, 2.5 miles north of Soda Springs. The photograph indications suggest this area to be a relatively large source of water under slight artesian pressure.

In addition to those mentioned above, old wells are also located near the resort pool house and at the Goat Farm. Except for data on historic water level elevations (no useful information recorded), we have not investigated these wells further as disintegrating well casings and general disrepair make such old wells uneconomical choices for increased water supply.

4.2 Water Table and Water Source

With the aid of the observation well network, we have constructed a contour map of the elevation of the water table at Soda Springs (see Figure 3). The elevation of the water table is shown in feet above mean sea level on June 8, 1985. Some later measurements were taken in the area of Three Bats Pond (wells S3, S4, S5 and F2 and the pond staff). These measurements, concluded on September 4th, showed no changes in elevation except for a 0.1

foot increase in water level in the pond as a response to the pumping of water to decrease the salinity during the late summer.

The earliest well and pond elevation measurements were taken on January 18, 1985. These measurements were similar to the June data at the water well S4, well S1, M.C. Spring and Three Bats Pond. In January the observation wells at the playa, P3 and P4, however were 0.5 and 3.8 feet higher, respectively.

In general, the water table contour patterns as shown are believed to be a good characterization of the local area. Where no nearby well or staff gauge data exists, the contour locations become less certain - as indicated by the dashed contours. As an example, those shown following around the south end of the limestone ridge are suggested from the aerial photo indication of moisture in the "Iron Springs" area. Also, the contour locations around Lake Tuendae are approximate as we have no well data there. The water table will vary with pumping to the lake. The trend between the southern area, defined by wells P1, S1 and S3 and the northern area, defined by wells S3, S4 and F2, is somewhat uncertain. The limestone ridge has a western projection, cut by the old railroad bed. If the projection drops below the ground surface gradually, it should create some interruption in subsurface flow.

Unfortunately, no wells were drilled to the west of the Three Bats Pond area before our study concluded. Present data suggests that the water table is about equally high along a north - south line through the water supply well until a point 150 feet south of the short road which runs westward into the palm groves. The two contour trends imply that the highest ground water levels should lie to the west of the area between well S3 and Three Bats Pond.

M.C. Spring has an elevation of 929 feet and the water level in well

F4 is at 932 feet. We have mapped two fracture surfaces as shown in Figure 3. Well F4 is located very near the northern fracture and M.C Spring is nearer the southern of the two fractures. As the fractures actually show slight displacement, and water elevations are similar at both ends, we believe that one or both serve as a conduit. The flow is small but it is sufficient to maintain relatively constant ion concentrations which are very similar to the supply well, S4. The fact that a surface water temperature of 19 C was measured in January when air temperature was -1 C, indicates a constant water supply from the aquifer.

Measurements made in March at new wells F1, P1 and S2 along with those of wells P3 and P4 described above, are the only ones showing a water level decline. F1, near the Soda Mountain edge, dropped only 0.6 feet. P1, in the playa sediments, dropped 0.9 feet. S1, dropped 2.7 feet and S2 dropped 0.8 feet. These changes are interpretated to mean that the primary water source for the Soda Springs area does lie north of a mild barrier created by the western spur of the limestone ridge.

The seasonal drops in all the wells located on or near the playa show that the water table aquifer system of the playa is recharged at a rate insufficient to keep up with the evaporative losses. The higher water elevations of wells S3, S4, F2, F4, Three bats Pond and M.C.Spring - and their lack of seasonal variance indicates independence from the playa water table. If the alluvial fan and adjacent mountains were the source of water, it might be expected that the fan water level should also drop somewhat as it would be lying on top of the playa water table. As this does not occur and our water analysis show a clear match to the deeper playa wells, we conclude that Soda Springs alluvial fan sediments are fed by vertical flows from zones a hundred or more feet beneath the playa surface (discussed in Section 3.4).

The system which provides this upward flow and its location is not known. As other seeps occur to the north, we tend to support the idea that the interface between mountain metavolcanic rocks and playa sediments is the conduit, perhaps made more effective at certain locations by a tongue of rubble shed off an unstable mountainside while the surrounding lake filled with fine sands and muds.

As a water supply question, the vertical conduit mechanism may not be especially significant if additional water supply goals are not intensive. The elevation data indicates that a north to south zone at least 1000 feet long, and centered on well S3 has a stable supply unaffected by the current pumping, evaporation and seepage losses.

4.3 Chemical and Physical Properties of Surface and Ground Waters

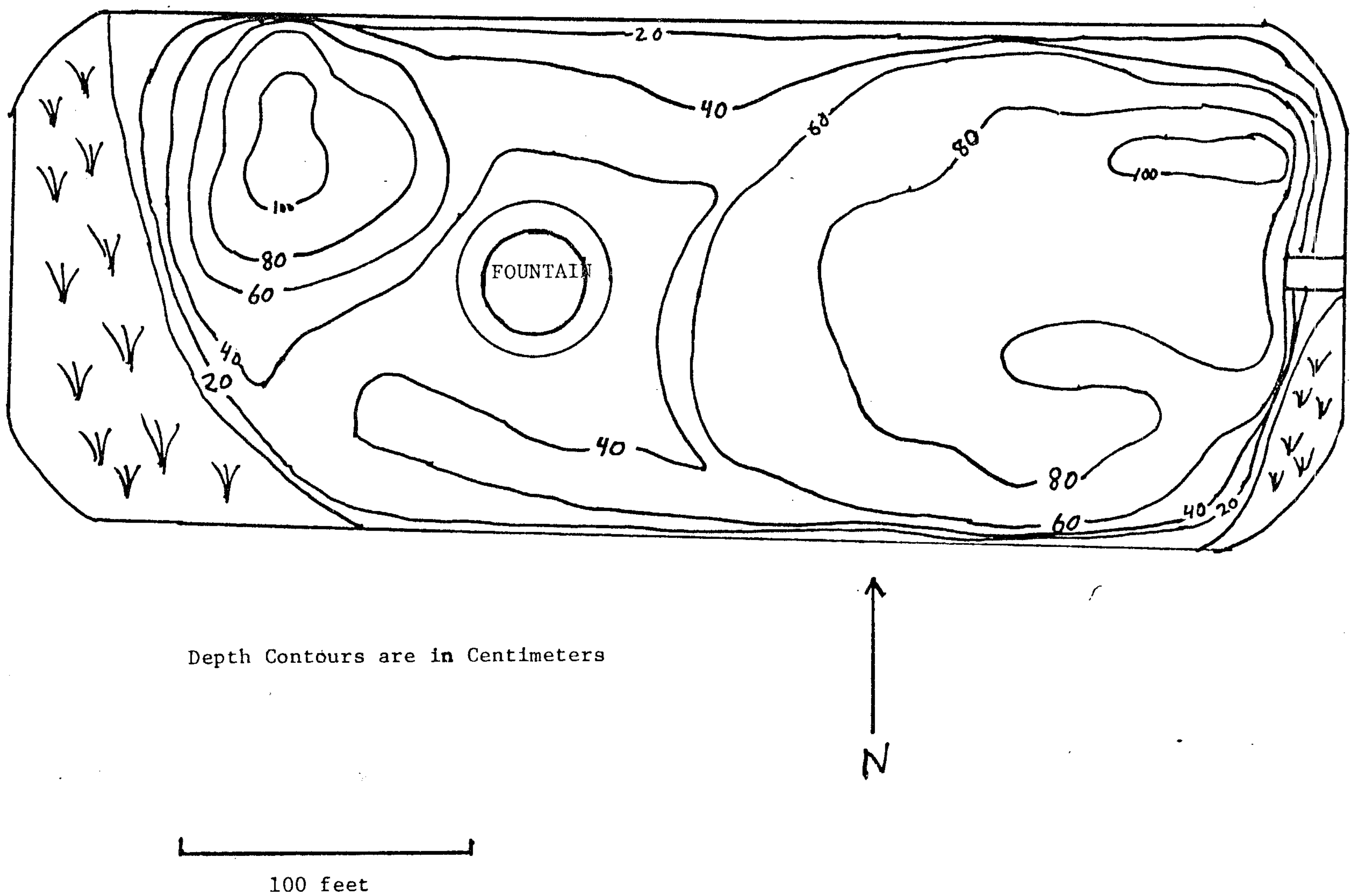
Surface Waters

Lake Tuendae, the largest pond and fish habitat at Soda Springs, has a surface area of 1.4 acres and a maximum depth of 3.3 feet. The lake was apparently formed by excavating a basin and pushing a berm up along its north side. A bathymetric map of the lake is presented in Figure 4. The deepest point is in the newly dredged area located in the northwest corner. This past winter the western end of the lake was dredged to create a deeper area to improve habitat for the chub. During the dredging process, pumping of water into the lake was stopped and the lake level was drawn down by pumping water over the north berm and out onto the playa. Water continued to flow into the lake by lateral percolation from the aquifer at a rate that prevented emptying of the pond.

The water in Lake Tuendae thus apparently comes from both the water table (aquifer) and from the supply well, S4. Evaporative water loss causes an increase in salinity but water loss due to bank flow out of the lake and the subsequent refilling with well water keeps the salinity well below that of the other major chub habitat, Three Bats Pond. During the winter months, lower air temperatures mean that evaporation rates are also much lower and the ionic composition of Lake Tuendae remains very similar to the supply well (see Table 5). Because Three Bats Pond has no outflow other than evaporation, its ionic concentration remains higher than Lake Tuendae, even in winter (see Table 6). In the warmer spring and summer months, evaporative loss causes a rise in salinity and in the general ion content of the lake due to concentration (see Tables 7 and 8).

The maximum salinity in Lake Tuendae remained below the potential lethal point for the Mohave chub during the summer of 1985. Physiological

Figure 4. Bathymetric Map of Lake Tuendae, Soda Springs.



Depth Contours are in Centimeters

Table 5. Chemical Constituents of Lake Tuendae and the Supply Well

Tuesdale Laboratories, Inc.

Sample Date: 22 February, 1982

	Lake Tuendae (mg/l)	Supply Well (mg/l)
Sodium -	776	766
Potassium -	21	19
Calcium -	25	23
Magnesium -	3.2	3.1
Bicarbonate -	310	317
Sulfate -	387	307
Chloride -	846	846
Fluoride -	10	10
Silica -	40	40

Table 6. Chemical Constituents for Soda Springs

Edward S. Babcock and Sons Laboratories

Sample date: 25 January, 1985

Parameter (mg/l)	Supply Well	Three Bats Pond	M.C. Spring
Sodium	760	2500	640
Calcium	25	10	14
Magnesium	7	5	6
Potassium	16	49	14
Sulfate	18	1050	240
Chloride	765	2414	607
Nitrogen	1.6	<1	1.4
Residue	2140	6720	1790
Arsenic	0.03	0.03	0.03
Boron	3.4	11	3.4
Hardness	92	46	60

Table 7. Chemical Constituents of Three Bats Pond and Lake Tuendae

Edward S. Babcock and Sons Laboratories

Sample Date: 1 May, 1979

	Three Bats Pond (mg/1)	Lake Tuendae (mg/1)
Sodium –	1000	920
Calcium –	28	22
Magnesium –	8	5
Potassium –	20	18
Sulfate –	450	440
Chloride –	1049	1007
Total Hardness	105	75
Total Alkalinity	339	227
Specific Conductance	4650 umhos/cm^3	4400 umhos/cm^3

Table 8. Chemical Constituents of the Well, Three Bats Pond and M.C. Spring at Soda Lake.

LABORATORY WATER ANALYSIS

Edward S. Babcock and Sons, Inc.

Samples collected 2 July, 1985

PARAMETER (mg/l)	LOCATION		
	Facility Well	Pond West	MC Spring
Calcium	23	8	15
Magnesium	6	10	6
Sodium	730	3450	650
Potassium	14	60	14
Bicarbonate	299	140	259
Sulfate	400	1300	295
Chloride	710	3650	690
Nitrate	5	110	4
Hardness ($CaCO_3$)	83	62	63
Arsenic	0.02	0.06	0.05
Boron	3.3	16	3.1
Hydroxide	-	-	-
Carbonate	-	625	-

tests performed on this species by McClanahan, et al. (1985), indicate that salinities above 10 parts per thousand (ppt) are lethal for the Mohave chub.

Dissolved oxygen levels in the open water areas remain high throughout the year. In the summer months, however, dissolved oxygen concentrations in the cattails at the west end of the lake, drop to levels as low as 1.0 parts per million (Soltz, 1979). Soltz found that chubs caught in traps in shallow water in the cattails died overnight, while those trapped in the adjacent open water areas survived. Low dissolved oxygen during the dark hours undoubtedly was the reason for the chub mortality.

Three Bats Pond

Three Bats Pond is probably a natural pond or seep area that had been enlarged by excavation. The average depth of the pond is 1.5 feet with the deepest area (about 4.0 feet) located in the southwest corner. The water in this pond apparently flows in by percolation from the water table. No pumping of water into this pond occurs except under extraordinary circumstances.

Evaporative water loss causes the salinity and ionic content of the pond to rise in the summer so that salinity levels sometimes reach 10 ppt (Vickers, 1973). During the winter months, the low evaporative rates allow water quality levels to improve so that chemical conditions are similar to those of Lake Tuendae.

A fish kill occurred in Three Bats Pond in August of 1981. Water samples taken in the fall of 1981 and analyzed by the California Department of Fish and Game, failed to indicate the cause of the mortality (see Figures 8 and 9). As mentioned, salinities as high as 10 ppm have been observed in this pond by Vickers (1973) and by Frank Hoover of the

California Department of Fish and Game in August of 1985 (Hoover, personal communication). High salinity may have been the cause of the 1981 fish kill. Also, dense beds of <u>Ruppia maritima</u> (widgeon grass) are present in the pond and the rotting of this vegetation may have lowered night-time dissolved oxygen concentrations, altered the pH or released sufficient ammonia into the water to cause the fish kill.

As mentioned in Section 4.1, the water levels in this pond decreased in the summer months of 1985 by 0.5 feet and the salinity reached 10 ppt. In response to a request by the Bureau of Land Management's Barstow office, we recommended the pumping of well water into Three Bats Pond in order to offset the increasing salinity due to evaporation and concentration. No fish kill occurred in 1985.

<u>M.C. Spring</u>

This small spring on the shore of Soda Lake also contains a population of Mohave chub (Soltz, 1979). The spring has a diameter of 18 feet and a maximum depth of 5 feet. Cattails encroach out into the water so that at times it is often difficult to see open water in the center of the spring.

M.C. Spring has water quality conditions similar to the supply well and it is connected to the Soda Springs aquifer by means of a large fracture in the limestone hill to the west. The temperature and chemical conditions of M.C. Spring are similar to the supply well and thus this small habitat has the best water quality conditions for Mohave chubs at Soda Springs. The physiological tests on temperature tolerance carried out by McClanahan, et al. (1985) indicate that the Mohave chub is not tolerant of extreme physical and chemical conditions. The critical thermal maximum and minimum for this species indicates that the Mohave chub prefers the moderate conditions of deeper water habitats or constant temperature springs. The fact that the Mohave chub dies in temperatures greater than 34 C and at salinities above 10 ppt, indicates that this species is not well adapted to the typical extremes in physical factors or water quality conditions of most desert aquatic habitats.

In an year-long study of the Mohave chub at Lark Seep on the China Lake Naval Weapons Station, we found that the chubs preferred deep channel areas (Feldmeth, et al., 1984). During the extremely hot or cold periods of summer or winter, the chubs moved out of shallow water. In fact, little chub activity was observed during the winter months. Laboratory tests on the ability of the Mohave chubs to swim in a water tunnel over a range of temperatures substantiated this observation. In temperatures below 14 C the chubs were capable of only limited swimming ability.

The almost constant temperature and chemical conditions of M.C. Spring make this a good habitat in terms of water quality. The small size of the spring, the presence of dense cattail growth and the lack of bottom or shoreline heterogeneity, however, only allow this spring to support a small population of Mohave chubs.

Ground Waters

The water quality at Soda Springs in the two main fish habitats, Lake Tuendae and Three Bats Pond, is apparently adequate in that the population has persisted here for a number of years. At times, conditions in Three Bats Pond become marginal in terms of salinity and a fish kill has occurred. But the quality of the water in the aquifer itself is relatively low in salinity and presents no problem in terms of naturally toxic substances such as arsenic, boron or heavy metals.

The question of potential impacts from increased use of the Soda Springs facility by the Desert Studies Consortium must also be considered. The presence of the leach line for the new rest room facility within the water table and almost adjacent to the water supply well may present a problem. Substances flushed down the sewage system could also make their way into the supply well or either Three Bats Pond or Lake Tuendae by means of lateral percolation. Although no problems exist at present in terms of contamination of either the well or the two main fish habitats, it is our recommendation that the leach line be relocated so that discharges occur to the north and west of Lake Tuendae at an elevation that will not allow waste water to flow into the aquifer.

4.4 Hydrologic Budgets of Water Bodies

In the following section we discuss the four surface water bodies as suitable habitats for the endangered Mohave chub. Calculations of water losses and recharge requirements are given and recommendations are made on the basis of optimizing the physical-chemical environment and minimizing pumpage and pond maintenance.

From our prior work on the physiological tolerance and habitat requirements of the Mohave chub (Feldmeth et. al., 1984) we have concluded that the Mohave chub has survived over the long term in an environment of stable and mild temperatures, stable and only moderately hard water, and normal range of dissolved oxygen. Unlike many of the fishes that are found in aquatic habitats in the deserts of the southwest.

Of the impoundments at Soda Springs, these conditions are best met at M.C. Spring.

M.C. Spring

We have estimated M.C. Spring to have a surface area of 250 square feet and a volume of 1000 cubic feet. The make up and chemical concentration of the spring water closely matches the supply well, indicating a flow sufficient to totally offset evaporation. As the spring is heavily covered with tall reeds, the water surface is protected from wind and sunlight effects. The usually quoted evaporative loss figure of 6.6 feet per year would produce a loss of about 1700 cubic feet - 1.7 times the volume. The figure is probably too high and may be on the order of 1000 cubic feet - one volume per year. As no doubling of salinity has occurred, the spring must be gaining and loosing water by horizontal percolation. Accurate measurement of this flow would require opening of the ditch and construction of a weir or other flow monitoring device. As an approximation we use the figure of 5000 cubic feet (0.1 acre feet), five volumes, as the amount percolating through the system to maintain constant salinity.

The hardness of the limestone making up the adjacent ridge produces little rubble which could fill in the spring and it is high enough to have not been filled with silt carried in the infrequent floods. The only immediate danger to the habitat is the heavy growth of cattails (Typha). The detrital buildup from this plant growth limits physical space as well as causing widely varying diurnal oxygen concentrations. We recommend that much of the cattails be cut and removed from the water. Some fringe can be beneficial as a means of reducing evaporative loss.

BLM Pond

In contrast to M.C. Spring, this pond showed an increase in salinity and a decrease in water level by mid-summer. It has an area of 900 square feet and a volume, when full, of 2700 cubic feet. As there is little protective growth surrounding the pond, the 6.6 foot evaporation figure is probably applicable. This gives an annual loss of about 6000 cubic feet -an annual loss equal to two volumes. The low elevation of the pond in relation to the playa surface and the fine particle size of the silty soil probably limits percolation losses. Recharge is probably from both the playa water table and the spring source. The spring source contribution is estimated to be on the order of 6000 cubic feet (0.1 acre feet).

Although located in close proximity to the stable M.C. Spring, this pond is not receiving an adequate recharge. To make it a suitable habitat more water might be supplied by cutting a trench to the south and east of M.C. Spring. With our present lack of knowledge on flow volumes, it is important to be prepared to take reversable actions at this location.

If a small channel is cut to bring in water from M.C. Spring we suggest monitoring spring level closely and retaining the capability to back fill the trench if a drop in M.C. Spring is detected.

Lake Tuendae

The lake has a surface area of 62,300 square feet and a volume of 80,000 cubic feet. It's size allows no protection from evaporative processes and the full 6.6 feet figure gives an annual evaporative loss of 410,000 cubic feet (9.4 acre feet), 5 times the lake volume. With the very high surface area to depth ratio, the lake should show rapid increases in salinity. Seepage loss of the blended lake and well water has kept a long term salinity build up from occurring. Aerial photos show the prominant seepage to the north and east from Lake Tuendae. This seepage is in part offset by pumping, but the lake must also be receiving significant groundwater recharge as high salinity has not be a major problem. Three Bats Pond, however, may be in an area of lower groundwater flow as it shows a strong salinity buildup and no measurable decline when the adjacent well is pumped.

The annual inflow of water to Lake Tuendae is estimated to be between 40 and 50 acre feet. The water supply well is estimated to pump about 40 acre feet per year, nearly all of which goes to Lake Tuendae (Stroud, Romspert, personal communication).

Lake Tuendae serves as an important element of the Zzyzx resort atmosphere. It does not, however, provide a good simulation of Mohave chub habitat. The most economical changes to provide more stable physical and chemical conditions would be deepening of some portion. A depth of at least four feet is needed to prevent invasion of cattails but unless a major portion of the lake has this depth, oscillations in oxygen concentration and temperature will continue. With the sizable surface area, natural aeration of the water is effective. Except for esthetic purposes, it is not useful to pump water to the lake through the fountain. Some water and fuel conservation could be affected by switching from the small pipes of the fountain to the available 3 inch line. Some evaporative loss would also be saved, particularly on windy days. The fact that water must be pumped into this pond almost daily to maintain sufficient water level and water quality conditions for the Mohave chub makes this an inefficient habitat for this endangered species.

Three Bats Pond (West Pond)

Three Bats Pond has a surface area of 41,000 square feet and volume of 90,000 cubic feet. It is only slightly sheltered and we assume looses a full 6.6 feet of water per year. That loss is 270,000 cubic feet (6.2 acre feet) and equals 3 pond volumes. Three Bats Pond has the highest chemical buildup of the four water bodies. In the winter months it maintains the same water elevation as the adjacent water well. By mid-summer evaporative losses cause it to lower about 0.5 foot. As it sits at the north side of the water well, this 0.5 foot differential demonstrates that lower levels in the 24 foot well are the more productive zones of the water table and the first 3 to 5 feet of sediment are only partially capable of transmitting water to offset salinity concentration.

As poor as its water quality history has been, Three Bats Pond probably offers the best area to replicate a Mohave chub habitat. Its location is near the probable artesian conduit, it is safely above the playa bed in event of flooding in Soda Lake and improved drainage could be provided. It is somewhat vulnerable, however, to flooding and erosion from the alluvial fan to the west. Some protection from local thunderstorm outwash can be implemented with large rock or lumber for example.

The design and implementation could be a research feature of the facility. Generally, the elements we recommend are:

1) Reduce the surface area to volume ratio to 1:5 or less to stabilize physical-chemical conditions.

2) Reduce the surface area for overall conservation of water until an adequate supply is demonstrated.

3) Dredge a major portion of the pond area to depths of at least 5 feet to provide stability and reduce bottom vegetative growth.

4) Construct a drainage channel, flowing perhaps into Lake Tuendae, for water conservation, or into the area of the temporary pond, if water quality isolation is desired. Include a control structure in the drain which allows selection of the elevation and volume of discharge.

5) Deepen the existing pond bottom at the western edge to gain additional flow as well as stability. Avoid deepening in the immediate vicinity of the water supply well to reduce the inflow from the pond to the well. We further recommend plugging of upper well casing holes, in any event, to reduce existing well contamination.

4.5 Water Well Supply and Expansion

The construction of the present well is not recorded with the U.S. Geological Survey or the California Department of Water Resources. It is a concrete cased, four foot square hole, approximately 24 feet deep. Water enters through holes about 2 inches in diameter spaced at broad intervals. We do not know if a gravel pack or similar design was used to increase well efficiency. Gasoline driven centrifugal pumps have been used. At the time of this report, new pumps are being installed. We do not have their specifications.

No long term records of well water elevations exist for this location. Other records, as discussed in Section 3.0, suggest some regional decline to be occurring. This decline may have had little impact at this location because of the small withdrawls and suspected large size of the artesian aquifer system. All measurements we have taken in the 1985 field work show that the well has always recovered to the 933 foot msl level after pumping. Recovery was not measured by us but apparently occurs within a few hours.

We conducted a pump draw down test on January 18, 1985. Such a test gives an indication of the transmission ability of the well and aquifer. As the well was pumped, measurements were taken of the water level in the well and in the two observation wells E1 and E2. We also measured the water level in Three bats Pond. The pumpage rate was measured by repeatedly timing the filling of barrels of a known volume. During this test, we discharged through an unrestricted 3 inch line. The measured rate was 218 gallons per minute. This is considered a maximum rate for the then existing pump as there was little restriction compared to the fountain and other water supply lines and the pump was operated at a higher throttle. This practice helps test efficiency, but calculations of yearly pumpage given below must use a lower figure.

Using the Jacob solution equations for transmissivity and storage coefficient, our test of the water supply well gives the following values:

Transmissivity = 100,000 gallons per day per foot

Storage coefficient = 0.13

Ideally, the transmissibility term describes a combination of permeability and thickness of the aquifer, giving the rate at which water is transmitted through the aquifer per foot of width. As we have no record of the sediment section penetrated by the well, utility of the figure is limited until future work provides a good description.

A value of 100,000 gallons/day/ft indicates a good supply of water, capable of increased production. We are cautious to depend upon these test data, however, the water table mapping and history of constant recovery to the 933 msl elevation support a conclusion that additional water supply capacity is present. If an additional supply of water is desired it is probably best obtained by the construction of a new well, somewhere to the south and west of the present location. Exploratory drilling is recommended, including additional well drawdown tests.

The storage coefficient is a measure of the volume of water released per unit volume of rock. In this case, one cubic foot of the Soda Springs well aquifer is calculated to release 0.13 cubic feet of water. This value is fairly typical for a coarse alluvial material.

Current and projected water usage can only be approximately calculated as pump hour logs have not been kept and the flow rates to the Lake Tuendae circuit are not knowm.

In discussion with the facility caretaker, the following usage was estimated:

June, July, August period, pump each day for approximately 3 hours.

September through May, pump 24 hours per week.

We measured a pump volume of 218 gallons per minute, but assume here, that reduced pipe size and throttle setting produce a volume of 175 gallons per minute.

June - August Period

175 gpm X 60 X 3 X 90 = 2,840,000 gallons (9 acre feet)

September - May Period

175 gpm X 60 X 24 X 39 weeks = 9,800,000 gallons (30 acre feet)

Total yearly pumpage under present practices is about 40 acre feet or 12.6 million gallons. Only a small fraction, less than 0.5 acre feet (130,000 gallons) is used for the bath house and pool according to estimates by Mr. Romspert (Romspert, personal communication).

From these calculations it is apparent that increases in visitor days will have no impact on the water supply. If changes are made in pond configurations as suggested in Section 4.4, water usage could decline. Expansions in the water supply for greater irrigation or other purposes seem possible as described above.

As no observation wells have been located west of Three Bats Pond, we do not know if there is any supply of water derived from local rainfall. The existing data gives no indication of such a supply, but the size of the alluvial fan might provide some groundwater. As a possible source of good quality water in addition to what will be available from the reverse osmosis unit, the possibility of a water supply well somewhere to the west of Three Bats Pond should be considered.

4.6 Effluent Discharges

We have been asked to consider the impacts of the two discharges at the site; the waste from the reverse osmosis unit and the leach line from the bath house and caretaker trailer.

As the playa water table aquifer is not a part of the Soda Springs system, flows to it will have no impact on the Mojave chub habitats. The small volume of the discharge compared to the evaporative loss from the saline lake bed will probably make its residue indistinguishable among the mottled pattern of the playa surface.

The bath house and trailer leach lines roughly meet at a point 100 feet south of the southwest corner of Lake Tuendae. From the water table data, both lines are submerged in the groundwater. Thier discharge therefore is carried as a plume northeastwards towards Lake Tuendae. As they are submerged, little, if any oxidation or uptake is occurring. Although the volume is small, accidental emptying of toxic materials into septic systems is not uncommon. Our system of test wells indicates that well pumping could draw leachate water into the water supply system. The current usage pattern has not, however, produced a groundwater conditions which would aid spreading towards the well.

We have detected a strong hydrogen sulphide odor in the well when the water level drops below the second set of inlet holes. Very little flow enters from these holes and they are stained the characteristic white of sulfide deposits. It is likely that anaerobic bottom deposits of Three Bats Pond are the source. However water table flows, particularly when influenced by pumping, are routinely irregular. Whatever the source, we recommend that the first two levels of well inlets be plugged to reduce this contamination threat. Because no pressure differential exists, simple wooden plugs and okum will probably work. Thought should be given to replacing the restroom facilities leach lines with blank pipe so that discharge sould occur at a location north or east of Lake Tuendae.

We do not know the construction of the kitchen drain. If located near the presently occupied kitchen, it should drain safely to the east. If the old pool well were to be re-used, the drain and well should be examined.

APPENDIX A

ELEVATIONS OF WATER LEVEL MONITORING NETWORK

In feet above Mean Sea Level

DESIGNATION	TOP OF CASING/STAFF	ADJACENT GROUND
E1	936.3	936.4
E2	936.2	-----
F1	935.9	935.4
F2	940.8	939.0
F3	933.1	931.4
F4	936.7	-----
P1	931.3	930.1
P2	931.1	929.3
P3	930.2	928.5
P4	928.7	926.9
S1	933.4	931.6
S2	937.7	----
S3	942.6	941.2
S4	936.5	936.4
S5	937.8	937.1
3 Bats Pond Staff	934.0	
Lake Tuendae Staff	931.3	
M.C. Spring Staff	930.2	
BLM Pond Staff	928.5	
